Recommendations for Refinement of a Spatially Representative Non-tidal Water Quality Monitoring Network for the Chesapeake Bay Watershed

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Introduction

Existing non-tidal water quality monitoring programs within the Chesapeake Bay watershed (CBW) do not meet the Chesapeake Bay's restoration priorities since a majority of these programs were only designed to address specific goals by various agencies. The Chesapeake Bay Program's Non-tidal Water Quality Monitoring Workgroup is in the process of designing a network for the non-tidal Chesapeake Bay watershed. This network is comprised of an inter-state group of surface water quality stations at which flow, and nutrient and sediment concentrations will be measured. To the extent possible, the network utilizes existing monitoring stations from state and federal monitoring programs. The proposed network is essential for measuring nutrient and sediment concentrations and loads and for assessing progress toward meeting the water quality criteria of the Bay and its tributaries (Chesapeake Bay Program, 2004).

The objectives of the monitoring network are to: 1) measure and assess the status and trends of nutrients and sediment concentrations and loads in the tributary strategy basins across the Bay Watershed, 2) provide quantitative measures of factors affecting nutrient and sediment status and trends in the basin and the effectiveness of BMP remediation efforts, and 3) improve calibration and verification of models used in the Bay Watershed.

In September 2004, the Chesapeake Bay Program's Non-tidal Water Quality Monitoring Workgroup completed the initial design of a sampling network for the Bay watershed. The initial selection of sites in the network focused on the rivers draining tributary strategy basin segments. The Workgroup developed a list of 188 candidate stations for inclusion in the network. These candidate stations include 115 existing stations and recommended locations for 73 new stations. To meet all three of the network objectives, each site in the network needs to have samples collected over a range of flow rates. Sites that meet these requirements are known as "primary" sites while sites that only meet the requirements for selected trend analysis are known as "secondary" sites. The network can be achieved through a combination of enhancing existing monitoring stations from State and Federal monitoring programs and by establishing new stations to meet the objectives and associated sampling requirements. As of May 2005 about 50 primary sites and 40 secondary sites have been established. It is believed that if all of the candidate stations were implemented, the CBP could address the objective of measuring the status and trends of nutrient and sediment concentrations and loads in the tributary strategy basins. However, it is not clear how well these stations address model calibration and verification issues or whether they would be capable of detecting and evaluating the effectiveness of BMPs designed to reduce sediment and nutrient loads to the Bay. To meet all the intended objectives of the network, there is a need to assess the spatial representativeness of current and proposed sites. In addition, due to limited funding available for development of the network, there is a need to develop criteria for prioritizing the implementation of new sites.

The Scientific and Technical Advisory Committee (STAC) was asked by the Non-tidal Water Quality Workgroup of the Chesapeake Bay Program Monitoring and Analysis

Subcommittee to discuss approaches and develop recommendations to improve the spatial representativeness of monitoring sites. This information would be useful in enhancing network design and in prioritizing the selection of future monitoring sites. More specifically, the stated purpose of this evaluation was to address the following broad questions: a) What guidelines should be considered by the CBP Non-tidal Workgroup to address the needs for spatial representativeness and selection of new sites for the network? and b) What changes need to be made to the spatial network to meet multiple network objectives and data analysis tools/models?

A Task Force was assembled to include members of STAC, USGS and other outside experts. On January 12, 2005, the STAC members of the Task Force held a telephone conference to discuss the role of STAC in assisting the CBP Program's Non-tidal Monitoring Workgroup. On May 9, 2005 Task Force members met at the USGS office in Baltimore, MD. After a series of very informative presentations by Scott Phillips, Steve Preston and Gary Shenk on network objectives, data collection, and data needs for various models and for developing environmental indicators, the Task Force members spent the rest the day exchanging information and ideas regarding the stated purpose of the meeting.

Representativeness of Monitoring Network: Definition

The most critical task in design of a water quality monitoring network is to ensure that the monitoring stations are spatially representative of watershed conditions and that they provide an accurate measure of the conditions of the ambient aquatic environment. Representativeness can be defined in a number of ways. In the context of this document, it is related to how well selected monitoring sites represent spatial variability in landuse/land cover, sediment and nutrient sources and other watershed characteristics that influence nutrient and sediment concentrations, discharge and loads.

Recommendations

An effective monitoring program is one that produces accurate, representative information at an acceptable level of effort and cost that meet program objectives. Such a program results from good planning, careful execution, and continuous review and evaluation (Mostaghimi, 2002; Mostaghimi et. al, 2002). The quality and usefulness of data collected from a monitoring program largely depends on considerations given in the planning phase of the monitoring network. However, it should be understood that the monitoring system design process is not static. Once data collection and analysis have begun, modifications in network design are often necessary. This is particularly true for maintaining the representativeness of the monitoring stations in the network and the rapidly changing landscape throughout the CBW. Therefore, it is essential that the monitoring goals and objectives be reviewed on a regular basis and network design adjusted accordingly. The following specific recommendations are made by the Task Force regarding the refinement of the non-tidal water quality monitoring network for the CBW:

1. In order to evaluate the representativeness of the current monitoring sites and make informed decisions regarding appropriate placement of future sites, there is

a need to conduct a comprehensive analysis of land use/cover upstream of each existing and proposed monitoring station in the network. There is also a need to conduct a reconnaissance of all relevant existing data sources from universities, other research organizations and regulatory agencies. An "existing conditions" report is an effective means to summarize the types of data available (including land use/cover) at each station and what is known about the current terrestrially-based impacts influencing the quality of water at each monitoring station. Such an "existing conditions" report would be invaluable in the selection of representative monitoring sites and the development of a list of data needed for comprehensive water quality assessment, trend analysis, and calibration and verification of computer simulation models being used in the Bay Program.

2. Location of monitoring stations in the network is extremely critical to the ability of the monitoring program to provide information representative of upstream watershed conditions. Therefore, considerable effort must be made in the design process to ensure that all target populations are sampled in a consistent and representative manner. The following criteria should be considered when prioritizing the location of existing and new sites within the monitoring network:

    - Land Use/Cover – Compile comprehensive information to characterize the upland land use/cover at each of the existing and proposed monitoring stations. Prioritize each land use/cover relative to its likely impact on nutrient and sediment production and stream discharge. Include in this prioritization an assessment of the likelihood of this land use/cover activity impacting stream quality at the monitoring site. Use this information to assure that all land uses/covers in the watershed are represented by the monitoring network over all geologic, edaphic, physiographic, and climatological regions of the CBW.

    - Utilize existing data, when available, and/or computer models to identify all pollutant sources in the upland areas captured by each monitoring station. Select future sites such that all sources of pollution in the Bay Watershed are well represented by the monitoring network. Regression techniques that relate water quality to other variables such as land use/cover, watershed size, and flow should be utilized to provide an assessment of all potential sources and causes of pollution (Preston and Brakebill, 1999).

    - Compile information on land use/cover projections for new or emerging "urbanizing" areas and increase the number of monitoring stations in these areas. At the same time, there might be a possibility of reducing the number of monitoring stations or the frequency of sampling in less affected areas, such as those dominated by forest cover.

- Other factors to consider in prioritizing the location of new monitoring stations should include rivers draining the outlet of tributary strategy basins; basin size; coverage and distribution among tributary strategy basins and component Bay model segments; climate; rainfall distribution; channel characteristics; and water travel time.

- Develop a comprehensive database on best management practices (BMPs) installed in the sub-watersheds, including their location, effective dates, and the remedial action taken. Locate some monitoring stations at the outlet of basins with intensive BMPs. This would allow for evaluation of the BMP impacts and assist with model calibration. If possible, sampling above and below a specific BMP or a combination of BMPs would be desirable.

- Utilize the factors and parameters listed here to develop a "Suitability Index" to rank the representativeness of existing sites and to decide on appropriate locations of future stations in the monitoring network. This suitability index should include specific references to the stated objective of the site with respect to network objectives.

- Use simulation models such as HSPF and SPARROW to identify the preliminary location of new monitoring sites. Results of the model simulations, combined with analysis of the existing data could provide sufficient information for identifying optimal placement of new monitoring sites (Bicknell et al., 1996)

3. The Bay non-tidal monitoring program maintains a "data requirement list" for model calibration. There is a need for enhanced integration of monitoring and modeling programs in an effort to improve the existing database for model calibration and application. If a major purpose of the monitoring program is to collect data for model calibration, it is preferred to have longer term, more frequent data from fewer monitoring stations than shorter term data from many stations. In some cases, however, the availability of both types of data bases might be desirable.

4. One approach for assessing the representativeness of a monitoring network is to develop a GIS database (e.g. flow rates, land use/land cover, population, upland area, etc.) of all stream segments representing the entire population of the non-tidal streams in the Bay Watershed and compare their characteristics with those of the network's sampling sites. A comparison of the frequency distributions of the stream segments of the population and monitoring network characteristics, such as drainage area; point source flow rates; discharge rates; population density; percent agricultural landuse; percent urban landuse, among others would indicate the degree of the representativeness of the network. Similarity in distribution frequencies of these parameters would indicate that the monitoring network

provides a spatially representative assessment of non-tidal streams in the Bay basin. Another factor that could provide some indication of the spatial representativeness of monitoring stations in the network is the spatial density of sampling sites (number of sampling sites per km^2 or number of sampling sites per million inhabitants). These ratios, while not comprehensive, could provide additional insights for final refinement of monitoring locations in the network.

5. The current sampling strategy was originally designed to support the ESTIMATOR model for computation of annual and monthly loads (Cohn et al., 1989). While ESTIMATOR is also used to compute trend in flow-adjusted concentrations, comprehensive analysis of the trends in observed concentrations may require a different sampling strategy (Langland et al., 2004). Additionally, in smaller basins different techniques for load estimation may be needed. Therefore, analysis of the different approaches for trend analysis and the optimum sampling strategy need to be investigated. Statistical analysis of existing databases should be conducted to determine optimum sampling strategy. Such analyses would include assessments of temporal and climatic variability to assess the optimal number of samples necessary to capture this variability for estimating loads. A monthly sampling frequency with additional storm event sampling is proposed for the non-tidal network. The ESTIMATOR model will be used to compute loads from these data. While ESTIMAOR is valid for larger river systems there are numerous load estimation techniques in the scientific literature that may be more appropriate for smaller rivers. . What method is most suitable for the CBP and what is the level of confidence given sites will address rivers of different size? Such information can be obtained from the analysis of an existing long-term database with frequent (perhaps weekly) observations.

6. In order to ‘‘assess the factors affecting nutrient and sediment status and trends in the basin’’, the effectiveness of remedial measures (BMPs) being implemented in the Bay watershed needs to be evaluated. This information is also needed for calibration and validation of the Bay’s computer simulation models. It is suggested that a targeted monitoring program be developed, as part of the monitoring network, to provide an assessment of the success of major BMPs being implemented in the Bay basin. A successful targeted monitoring program must allow for identification of when and where the implementation of these actions is likely to be successful. To meet this objective, monitoring sites should be identified based on key watershed characteristics (such as climate, soil type, landuse, stream order, geology, and topography) and their ability to provide pre- and post-implementation assessment of major BMPs. In general, if one of the purposes of the monitoring program is to assess the effectiveness of BMPs, and/or use the data to calibrate models, it is better to locate the monitoring stations at the outlet of smaller watersheds to allow for collection of more intensive data. This approach would also assist in improving functional features of model components. Furthermore, it is suggested that flow-weighted storm event sampling should form the basis of the targeted monitoring program. The first step in implementation of a targeted monitoring program should be the development of

a comprehensive database on type, condition, age and location of existing BMPs in the Bay basin. However, to the extent possible, it is recommended that data from past and current studies on BMP effectiveness be utilized to complement the Bay's monitoring and modeling goals.

7. The Chesapeake Bay Non-tidal Watershed Water-Quality network is composed of an inter-state group of surface water stations at which flow and nutrient and sediment concentrations are measured. The network was built from existing State and Federal monitoring stations, each with their own different requirements (Chesapeake Bay Program, 2005). Thus, it is critical that uniform sampling, data collection, and analysis procedures be defined, and then used, to enhance the compatibility of data among various stations. A draft document was recently developed in an effort to establish uniform QA/QC activities for field data collection and laboratory analysis (Chesapeake Bay Program, 2005). It is recommended that this draft document be expanded to include data analysis procedures and be looked upon as a "living" document that will be reviewed and updated on a regular basis. Furthermore, it is suggested that regular training sessions on QA/ QC procedures be conducted for all personnel involved in the monitoring program. It is important for the Bay Program to develop a set of uniform Standard Operating Procedures (SOPs) for discharge measurement, field data collection, sample collection, sample handling and transport, sample analysis, data reporting and management, and data analysis. For data compatibility, it is essential to include as much uniformity as possible in this network of the multitude of state and federal agencies that will be involved in monitoring. Thus, it is recommend that the non-tidal water quality monitoring program utilize the services of a central analytical laboratory for the analysis of all water quality samples collected by the monitoring network.

8. It is recognized that, due to potential lack of sufficient spatial representativeness of the existing station network, there might be a need to install new monitoring stations in the network. A key consideration in expanding a monitoring program is cost. The installation of flow monitoring stations can be one of the most restrictive components of a program. Therefore, it is recommended that a comprehensive incremental cost analysis of upgrading existing monitoring sites (e.g. adding chemical monitoring to existing flow monitoring sites) versus development of new sites be performed in an effort to reduce the cost of developing the network.

9. Due to physical, technical, and cost limitations, there is a general lack of sufficient monitoring sites in the Coastal Plain region (below the fall line). Information from the Coastal Plain, however, is particularly important due to the fact that these areas are located adjacent to the Bay, and human activities in these areas could have more direct and severe impacts on the quality of water in the Bay. Furthermore, a large portion of water entering the Bay from these areas is through subsurface (groundwater) flow, which is not currently being monitored

by the existing monitoring programs. Thus, it is critical that resources be sought and new monitoring techniques and procedures be investigated to adequately characterize sediment and nutrient loadings to the Bay from these areas.

10. The current method of streamflow monitoring which was developed in the 1800s requires the physical measurement of channel geometry and velocity distribution at a cross-section of a stream. A stage-discharge relationship is developed through repeated measurements, and future stream discharge is then indirectly computed by measuring water surface level (stage). The initial "direct contact" method of measuring discharge to develop the stage-discharge relationship involves extensive labor and requires frequent traveling to remote stations. Thus, a significant portion of the monitoring program is devoted to collection of discharge data. Furthermore, the requirement of direct contact with water and stream frequently exposes field personnel to potential hazards and the monitoring equipment to harsh conditions. The expanded Chesapeake Bay non-tidal monitoring network should place particular emphasis on using new "non-contact" monitoring technologies to achieve objectives of lower costs, increased reliability, and safety. These non-contact methods also have the advantage of enabling more frequent flow measurements which could result in better data accuracy, or the cost savings could then be invested in increasing the frequency of nutrient and sediment samples, or in additional monitoring stations. These non-contact technologies include acoustic devices, laser technologies, image methods, low frequency radar, and high frequency (microwave) radar (Cheng et al. 2002). Efforts and resources should also be invested in utilizing sensor technologies and automated water samplers to enable increased sampling frequencies during storm events at selected monitoring stations. Likewise, the use of in-stream water quality probes at selected sites is highly encouraged. While the accuracy of the existing probes is still a limitation, they may provide insight into temporal variability that would be useful in evaluating the representativeness of the infrequent grab samples, especially during storm flows.

11. A key requirement in developing a successful monitoring program is availability of sufficient fiscal resources. If the budget is insufficient to meet the stated monitoring objectives, then either the objectives have to be simplified or funds should be redirected to accomplish the expectations. Thus, there is a need to prioritize the objectives of the network to be able to respond to situations where funding is severely limited. Given the scale of downstream economic consequences of nonpoint source pollution from non-tidal areas of the Bay watershed, it is absolutely necessary to address issues regarding the inadequacy of fiscal resources for development of a comprehensive non-tidal monitoring network.

12. Finally, we recommend that regular reviews of the Bay's non-tidal monitoring network be conducted by internal as well as external experts to ensure that the stated monitoring objectives are being accomplished.

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